A PETROGRAPHICAL SKETCH OF ÆGINA AND METHANA.

PART II. PETROGRAPHICAL DESCRIPTION.[1]

Classification.—While limestones and other non-eruptive rocks occur in the region at present under description, yet they offer no special features of interest and will not be touched upon further. What will chiefly engage our attention are the eruptive rocks proper which make up by far the greater part of Ægina and Methana, with the eruptives from the neighboring and closely related localities of Poros and Kolautziki. Some space will also be devoted to the segregations found in the lavas and to the tuffs.

The eruptive rocks may all be referred to the two well defined groups of andesites and dacites, but a few words must be devoted to the classification here adopted before we begin their description.

The distinction between the two main groups, as defined by Zirkel,[2] does not depend solely on the presence or absence of quartz but on the superabundant amount of SiO_2 whether it has crystallized out or not, exactly as is the case with the trachytes and rhyolites. In the case of the rocks before us there is, as usual, some difficulty in drawing a fast line between the two; but, as a basis for the distinction I have used the percentage of silica, those rocks having over 62 per cent. being classed as dacites, those with less as andesites. As it was impracticable to have analyses made of all the specimens I have had to judge in some cases by the presence or absence of quartz grains, or by analogy and association, so that, though we may be left in doubt in a few cases as to where to place a given specimen, yet on the whole the discrimination is made with comparative ease, and the

[1] Continued from Vol. II., p. 813.

[2] ZIRKEL, Lehrb. v. Petrog. 2d ed., 1894, p. 569.

errors will not affect the general conclusion that may be drawn from the observations.

The sub-classification of these two main groups allows of more latitude, but is readily done by means of the ferro-magnesian silicates, the writer preferring this to a classification based on structure such as Rosenbusch adopts for the dacites.[1] It must be borne in mind that between some of the groups gradations occur, though on the whole there is less difficulty from this source in the present district than in many others. In the final classification then I have followed in the main that of Küch[2] for the closely similar Colombian eruptives, though my scheme differs from his in distinguishing between the augite and the hypersthene-andesites.

I divide then the dacites into: *Hornblende-Dacite; Hornblende-Hypersthene-Dacite*, and *Biotite-Dacite.*

The andesites are divided into: *Hornblende-Andesite; Biotite-Hornblende-Andesite; Hornblende-Augite-Andesite; Hypersthene-Andesite*, and *Hornblende-Hypersthene-Andesite.*

It may seem unwise to give a mixed, and from a certain point of view a subordinate, group like the last as much prominence as a chief group such as the hornblende-andesite; but, leaving other considerations aside, it must be remembered that the present classification is merely for purposes of description in this paper, and not intended for general use. It has the further advantage, in the present case, of making the petrographical groups correspond, to a large extent, with their geological and geographical divisions.

Hornblende-Andesite.—Rocks belonging to this group compose the whole of the Stavro district, *i. e.*, Mts. Stavro, Palæochora, and Spasmeno Vouno, and are found as well along the north slope of Mt. Chondos, or Mt. Dendros, and at a small hill south of Kakoperato. While these various occurrences greatly resemble each other fundamentally yet there are certain small differ-

[1] ROSENBUSCH, Mikr. Phys. II., 1887, p. 638.

[2] REISS and STÜBEL, Reisen in Süd Amerika. Geol. Stud. i. d. Rep. Colombia, I., Petrographie. 1. Die Vulkanische Gesteine von R. Küch, Berlin, 1892, pp. 18 and 19.

ences. The rocks of the Stavro district, on account of their quantity and importance, will be taken as the type and described in detail.

Megascopically they show a largely preponderating light gray groundmass with a slightly pinkish cast which is dull in luster but very compact and fine grained, there being no gas pores or vesicles. The specific gravity of the Stavro rock is 2.508, that of Spasmeno Vouno being 2.327. The latter differs slightly from the former in being of a purer gray color and with groundmass rougher in feel and not as fine grained.

Quite abundant phenocrysts are scattered through this groundmass but with no trace of arrangement in lines of flow. The majority of these are greenish black hornblende prisms from 0.5–2.0 mm. long. There are also seen a few stout, black, hexagonal prisms of biotite measuring 3–5 mm. each way, the interior of these often containing minute white grains which seem to be plagioclase. Many plagioclase phenocrysts are also present, of a dull white color and showing cleavage faces and occasionally twinning striations. In the specimens from Spasmeno Vouno are seen three or four pink quartz grains about 2 mm. in diameter, not surrounded by an augite fringe.

No segregations ("endogenous enclosures") were seen in the whole district. In one or two specimens there are yellowish green streaks colored by epidote and due to subaërial decomposition, and some of the plagioclase phenocrysts are colored yellow from the same cause. The rocks of Spasmeno Vouno are all more decomposed than those of Mt. Stavro, the best specimens from which are quite fresh.

The hornblende-andesites from the other localities differ from those just described chiefly in the greater abundance and larger size of the phenocrysts, among which also plagioclase is the most important; the groundmass resembles, as a rule, that of Spasmeno Vouno, being not very compact and rough in feel. One or two of the specimens from Mt. Chondos are decomposed and of a pinkish brown color.

Under the microscope these andesites show a groundmass

made up, to a large extent, of colorless or very pale brown glass base, this being much more abundant in the Spasmeno rock than in that from Stavro. In this base are strewn quite abundant plagioclase lathes[1] and small colorless microlites, some of which seem to be augite, many small magnetite grains, and (especially in the Stavro rocks) much brown "dust" in streaks and patches. A flow structure is developed among these smaller constituents, which is especially well marked in the Spasmeno rocks, where also the "dust" is almost entirely absent. There are also to be reckoned among the groundmass constituents a number of small plagioclase crystals and green hornblende prisms.

The discrimination between the phenocrystic and the groundmass plagioclase is quite easy, as the latter is almost always in the shape of small clear lathes, while the former is in much stouter crystals and generally with inclusions. The plagioclase phenocrysts are of fair size, and, under the microscope, seem quite fresh and unaltered. The stout crystals show the usual planes and very few fracture surfaces are to be seen. Twinning lamellæ, in nearly every case according to the albite law, are common and the extinction angles of 29°–30° 30′ on *c* (001) indicate that we have here a bytownite of about the composition $Ab_1 An_4$, though in all probability other members of the series are present. Such a basic plagioclase is unusual for hornblende-andesite whose feldspar is generally labradorite or andesine, and I very much regret that the lack of proper facilities in Venice, where this paper was written, prevented the examination of the feldspar by other methods. The small lathes also belong to the bytownites, but at the end of the series richer in albite. Zonal structure is quite frequent.

Inclusions are very common in the larger crystals and in the great majority of cases are of generally clear brownish glass, occasionally dusty, and frequently holding a bubble. In many cases these glass inclusions are so numerous that they form a

[1] The term "lathes" is used for the larger, but still small, long groundmass crystals (especially of feldspar), while microlites are the smallest in size and in many cases of an indeterminable nature.

sort of "network" of the plagioclase, the meshes being of glass. This "net" usually forms a core of the same shape as the crystal with a narrow, clear, inclusion-free zone of plagioclase surrounding it. In other cases there is a central core of clear feldspar, then a "network" zone, and finally an outer clear border. Belowsky observed similar inclusions in the feldspars of andesite from West Ecuador,[1] and they are not infrequent elsewhere. Besides these glass inclusions some small clear hornblende crystals, magnetite grains and apatite needles are also to be seen as inclusions in the feldspar.

One of these apatite inclusions which is of special interest consists of a slender prism with low pyramidal terminations, .025 mm. long, from one side of which projects a smaller prism at an apparent angle of 47°. This must be regarded as a twin and identical with the apatite twin from North Carolina[2] described by me, with twinning plane *s* $(11\bar{2}1)$ and the angle between the *c* axes of 68° 28′. The lesser angle in the present case is accounted for by the fact that the twin does not lie with the plane of its two axes parallel to that of the section, as is seen on the use of higher powers. This occurrence is interesting since it serves to confirm the view that the first described case was a true twin and that the plane *s* $(11\bar{2}1)$ is a twinning plane of the species.

The hornblende of these andesites, which occurs in well shaped, though often broken, crystals (the uncommon plane *a* (100) being often largely developed) is noteworthy on account of its color. This is a light, rather bright, olive-green, the pleochroism being very strong; **c** dark olive-green, **b** olive-green, **a** pale yellowish green. This color is characteristic of the hornblende of all this group, with the exception of one specimen from Mt. Chondos which seems to have undergone decomposition to some extent. Here the hornblende is of a dark or brownish green color, and the very strong pleochroism is: **c** dark orange-

[1] REISS and STÜBEL, Reisen in Süd Amerika. Das Hochgebirge d. Rep. Ecuador I. Petrog. Untersuch. I. West Cordillers, Tulcan bis Escaleras Berge von M. Belowsky, Berlin, 1892, p. 28.

[2] Am. Jour. Sci., XXIII., 1887, p. 504. *Cf.* DANA: Mineralogy, 1892, p. 767.

red, 𝔟 dark red-brown, 𝔞 light yellow-green. In this case it must be noted that some of the hornblendes are of that dark red color which, as Belowsky[1] has shown, is produced by heating the green variety. The occurrence of green hornblende in the andesites is rather unusual, the color being generally brown. As is well known the green color is characteristic of the propylites, but the present rocks show none of the well marked features of this group, and are in every other way typical hornblende-andesites. The extinction angle is 11°.

The hornblende is in every case, except that mentioned above, perfectly fresh and unaltered, the dusty edges of some of the crystals, which look at first sight like incipient alteration, being seen on closer examination to be due to overlapping layers of the dust-laden groundmass. Zonal structure is occasionally seen, some of the crystals having the commonly observed darker green core. Inclusions are not common and small, though of considerable variety; small crystals of biotite, augite, plagioclase and magnetite, with an occasional zircon or spot of brown glass, having been noted. The distinction between the phenocrystic and the groundmass hornblende is hard to draw as they grade into each other with no difference of habit.

Augite is not abundant in these rocks, though occurring here and there in small crystals, clear and almost colorless. Intergrowths of this with the hornblende are not unusual, in one case the augite occupying the center and the hornblende forming the outer part of the mixed crystal; while in other cases one end is augite and the other end hornblende. A very few sections of biotite were seen in the slides; they are greenish gray, quite fresh, and carry inclusions of plagioclase and magnetite.

Magnetite is quite abundant in the form of fine grains in the groundmass as well as larger crystals up to 2 mm. in diameter. These last not infrequently show inclusions of plagioclase, apatite and zircon, and even, as in one case, have grown around the present groundmass. Many of these larger crystals show a coppery brown luster by reflected light, and, on the edges and

[1] BELOWSKY. Op. cit., p. 37.

in the thinnest spots, a granular structure, the grains being semi-transparent, of a chestnut-brown color and isotropic between crossed nicols.

The fresh appearance of the rock and the crystals, and the absence of a surrounding border of brown limonite, seem to preclude the idea that their appearance is due to weathering, though they somewhat resemble the limonite pseudomorphs after magnetite observed by von Lasaulx[1] in some altered basalts from the Auvergne. In color and physical characters the grains bear a great resemblance to the crystallites in the Bobenhausen tachylyte[2] which Zirkel[3] holds to be an extremely ferruginous glass. It may be, then, that these large magnetite crystals are in reality pseudomorphs of such a glass after the original magnetite, due to the combination of the latter with the magma.

A curious fact is that the majority of these larger magnetite crystals are accompanied by perlitic cracks in the groundmass, which surround the magnetite at a short distance from it either completely or partially, there being sometimes only one and sometimes several such cracks about each grain. These cracks are not met with elsewhere in the groundmass, nor do they surround any of the other minerals, and their formation may be connected with the brown coloration and granular structure just described. It must be noted that the groundmass between the cracks and the magnetite grains, quite up to the latter, is entirely normal and identical in color, structure, etc., with that elsewhere.

In addition to their green hornblende these andesites are specially marked by the presence of tridymite, which is very common, especially in the rocks of the Stavro district. This occurs in small irregularly-shaped masses or round rosette-like clusters showing the usual shingle structure, or in radially arranged spherical aggregates, about 0.1 mm. in diameter. As they often occupy the sides of small cavities they seem in part to be of secondary origin, but this is not at all certain.

[1] Neu. Jahrb., 1870, p. 695.

[2] *Cf.* VOGELSANG, Die Krystalliten, Bonn, 1875, p. iii., and Pl. XIV., Fig. 1.

[3] ZIRKEL: Basalt Gesteine, Bonn, 1870, p. 182, ff.

The above description will apply on the whole to the hornblende-andesites from the other localities, though in these last the phenocrysts are much more abundant. In two of the specimens, from Mt. Dendros and from the ridge southwest of the monastery, the groundmass is markedly spherulitic. The spherulites belong to Vogelsang's globospherites, being rounded aggregations of brownish dusty globulites and some trichites, arranged so as to give to the spherulite a fine radially fibrous structure. Surrounding this fibrous granular center, which has no action on polarized light, is a narrow border of clear, colorless isotropic glass substance. The groundmass of these spherulitic andesites is very vitreous, and with many perlitic cracks.

Biotite-Hornblende-Andesite.— The only representative of this group is the rock which forms the small promontory on which stands the town of Poros. Megascopically the specimens resemble much more the lighter hornblende-augite-andesites than the rocks just described, having a fine-grained gray groundmass containing very many plagioclase crystals and small hornblende needles. In this—generally arranged in lines of flow—are very numerous phenocrysts, chiefly of white plagioclase with stout black hornblende prisms and many biotite tables; grains of quartz are very rare. Much of the rock is partially decomposed and then assumes a reddish brown color, the plagioclase being tinged with yellow, and the biotite tables acquiring a brilliant submetallic bronze-luster resembling that of phlogopite.

Under the microscope they show a groundmass of largely preponderating colorless glass base, containing many small microlites chiefly of plagioclase, with plagioclase lathes, small, fresh, greenish brown hornblende crystals and but little magnetite Flow structure is beautifully developed in the groundmass, and segregations are quite frequent.

The phenocrysts of hornblende are of the same greenish brown color and perfectly unaltered; in the decomposed specimens however being decidedly brown, with no traces of a green tone, but still remaining perfectly clear. Biotite crystals are quite common, of an olive-green color when unaltered, but in the

less well preserved specimens of a reddish brown or brilliant orange. Some of them are bent and show frayed ends. The plagioclase calls for no special remarks; twinning lamellæ are common and the extinction angles of nearly 30° show that it is a bytownite. A few clear colorless augite crystals are also present.

The rock from this locality has been described by R. Lepsius[1] who states that the feldspar is orthoclase, does not mention the very abundant hornblende, states that the rock contains 60.21 per cent. of SiO_2, and calls it a trachyte and the same rock as that which occurs at Kalamaki and Kolautziki, which last, as we shall see later is not the fact. He seems to have examined but one hand specimen, and that more or less weathered. My study of the rock *in situ* and of the three specimens brought back with me does not bear out his view that it is a biotite-trachyte. The feldspar is all, with scarcely an exception, undoubtedly plagioclase, hornblende is abundantly present, and the slightest comparison of the specimens in my possession show that the Poros and the Kolautziki rocks are quite different. It is possible that Philippson may have collected a specimen quite different from mine, but if so it must be of a subordinate facies and not from the main mass of the Poros dome. In the few hours which we spent at Poros I went over most of the small hill and found only the rocks such as have been described above. The main body of the rock of Poros must then be with certainty regarded as a biotite-hornblende-andesite and not as a trachyte.

Hornblende-Augite-Andesite.—The chief rocks of the central part of the island of Ægina belong to this group as it makes up the main part of Mts. Chondos, Pagoni, Dendros and Gaiapha, with probably many of their outlying spurs.

Megascopically they differ considerably from the rocks to the north and south of them, showing a highly porphyritic structure with very numerous phenocrysts, the latter being in some cases so abundant as to give the rock almost a granitic appearance. The phenocrysts are almost entirely plagioclase, with few hornblende prisms and still fewer biotite tables, no quartz grains

[1] PHILIPPSON. Op. cit. p 604, *cf.* ZIRKEL, Petr. p. 258.

being seen in any of the specimens. The groundmass is almost without exception dark gray, in some of the Mt. Chondos specimens almost black, quite compact and occasionally with a subgreasy luster. The rock near the tuff at the west end of Mt. Chondos shows a banded structure of alternate dark and light gray streaks,which run almost vertically; they are best brought out on slightly weathered surfaces.

The only exception to the above general description is the hornblende-augite-andesite specimen from a small hill or ridge southeast of Kakoperato, which is much less compact in texture, lighter in the color of the groundmass, and shows a great many phenocrysts of hornblende.

All these andesites show a great tendency toward decomposition, becoming dull, more or less friable, and of a light reddish or purple color. Endogenous enclosures are quite common in the rocks of this group and will be described later.

Under the microscope the groundmass of these rocks is seen to be not typically hyalopilitic, but consisting of a glass base which is either colorless or brown according to the megascopic appearance of the rock, containing numerous microlites of plagioclase and augite with many magnetite grains and very much fine globulitic "dust." In the groundmass are also seen many larger plagioclase lathes, with small, stout, colorless augite crystals, and fewer small hornblende crystals, many of which are quite fresh and of a yellow-brown color, while others are altered to a dark opacitic mass either on the edges or completely. Here again while the distinction between the groundmass and phenocrystic plagioclase is easy on account of their diverse habits, as in the Stavro rocks, in the case of the augite and hornblende the line of demarkation cannot be sharply drawn, and the distinction is almost entirely a question of size, though the difference in the amount of alteration in the small and large hornblende crystals is of some assistance.

Augite occurs in not very large, usually well shaped crystals, showing the common planes of a clear and extremely pale brownish yellow color, so faint as to be almost colorless. In

some of the more decomposed specimens they are colored yellow or reddish brown on the edges. No pleochroism is to be observed, and the extinction angle is decidedly high, in many cases reaching or surpassing 45°. Hour-glass structure is not uncommon, though never well developed. Though the crystals are as a rule simple, yet twins, generally with the twinning plane *a* (100), are to be noted; and in some cases interpenetration twins, of two prisms crossing at angles of about 76° and the clino-pinacoids being parallel. These apparently have the twinning plane *c* (001), and resemble the augite twins described by Elich[1] in andesites from Ecuador.

The crystals are frequently grouped in clusters of irregular shape, and with no definite arrangement of the component crystals, somewhat resembling in structure, but not mineral composition, the clusters of Judd's glomero-porphyritic structure.[2] These again sometimes assume the form of rings of augite crystals (sections of spheroidal shells), which surround a nucleus of clear, colorless substance which generally shows perlitic cracks and only rarely exhibits a faint double refraction. This is without doubt glass, and in the few cases where it acts on polarized light the effect may be caused by a state of strain due to the growth of the augite shell. Projecting into this glass nucleus from the inner edge of, and at right angles to, the augite ring, are small colorless or greenish prismatic crystals, which present all the characteristics of augite. They resemble the augite fringes often seen around enclosed quartz grains and may be of secondary origin.

The hornblende of these andesites belongs to the brown variety and megascopically much resembles the so-called basaltic hornblende, though the color is blacker and the surfaces more glistening.

Microscopically they are seen to be larger than the green

[1] REISS and STÜBEL. Reisen in Süd America. Das Hochgebirge, I. Rep. Ecuador, I. West Cordillers iii., atacatzo bis liniza von E. Elich. Berlin 1893, p. 157, Pl. iii., Fig, 4.

[2] JUDD. Q. J. Geol. Soc. XLII. 1886, p. 71.

hornblendes of the hornblende-andesites or than the augite crystals accompanying them, and to have been originally well shaped stout crystals, without the orthopinacoid. The color is a pale yellow-brown, with strong pleochroism; $\mathfrak{c}$ yellowish brown, $\mathfrak{b}$ yellowish brown, $\mathfrak{a}$ colorless, the absorption being $\mathfrak{c} \geq \mathfrak{b} > \mathfrak{a}$. In some of the hornblende-augite-andesites of Mt. Pagoni an intermediate type is seen, of a greenish brown color, which, however, resembles more the brown than the green variety. The extinction angle of the brown variety is lower than that of the green, varying from 5°–6° 35′—a fact quite in accordance with the observations of Belowsky, to be mentioned later. Inclusions are not common.

This brown hornblende, as has been so often noticed, is decidedly prone to alteration. While most of the small crystals which occur in the groundmass are either quite fresh or only altered on the edges, the larger crystals, even the largest, which may be ten or many more times the diameter of these smallest ones, are entirely altered (or with only a small unaltered core) to a very fine-grained almost opaque, black mass of augite and opacite (magnetite) grains. The further stage of alteration to a more coarsely granular augite-magnetite aggregate is not generally seen in these rocks. Notwithstanding their alteration the original sharp outlines of the hornblende have been excellently preserved.

This alteration is so familiar and has been so often described that it is unnecessary to dwell upon it here at any length. One or two points call however for special mention. The presence of the small, unaltered crystals along with much larger altered ones points to the conclusion that not only were the large ones altered at a quite early period, but that the small ones were formed subsequently to, and under different conditions from, the alteration of the larger ones.

I observed also in many cases of juxtaposition between hornblende and feldspar that the presence of the feldspar had no effect on the alteration, this being as great at the surface of contact as along the free sides of the hornblende crystal. This differs some-

what from the observation of Küch[1] that hornblende in contact with microfelsitic groundmass was unaltered, while next to vitreous groundmass it had been altered, this being seen even in the same crystal.

A few words in regard to the difference between the brown and the green varieties of hornblende. Belowsky,[2] on the basis of some very valuable and interesting experiments of his own, puts forward the view that the brown is chiefly produced by alteration of the green "through the action of heat, in which oxidation was possible." Against this view must be brought up the fact that here in Ægina we meet with both varieties, but never in the same rock species. The green is characteristic of the *pyroxene-free* hornblende-andesites, and where this has undergone alteration, as in the case from Mt. Chondos, described on page 25, the resulting form of hornblende is quite different from the brown variety just described, which is the characteristic hornblende of the *pyroxene-bearing* andesites. This correlation of almost colorless pyroxene and brown hornblende, which is well established in the rocks before us (and, I may add, in the closely analogous augite-andesites of Smyrna and biotite-andesites of Pergamon), shows that the formation of the different varieties of hornblende is dependent on the different chemical constitutions of the magmas, and on the different conditions, which in one case determined the crystallization of the ferro-magnesian molecules as pyroxene and brown hornblende, while in the other they crystallized out as green hornblende, with or without biotite, and with little or no augite.

That the green hornblende on heating assumes the color and extinction angle of the basaltic hornblende is not to be denied, but in view of the facts above mentioned, and the vague and unproven character of the difference of heat conditions in the formation of the different varieties of hornblende, it is surely too much to infer from this fact that the brown hornblende is always derived from the green by alteration of the latter, and cannot have an independent origin and existence of its own.

[1] KÜCH. Op. cit. p. 55. Pl. V. Fig. 6.

[2] BELOWSKY. Op. cit. p. 37 ff.

It must further be remembered that the green hornblende was itself formed and existent in a magma at a temperature undoubtedly much higher than that of the simple Bunsen burner employed by Belowsky; but whether in the absence of oxygen or not we cannot perhaps say, though in view of the well established presence of water in most lavas and its probable dissociation at the high temperature of the liquid lava in the conduit oxygen may reasonably be supposed to have been present. At any rate, in the case of two lavas erupted under such similar conditions as those of Stavro and Chondos there is no ground for assuming that the latter was at a higher temperature than the former,[1] or that the one was oxygen-free and the other not. Again, it is difficult to explain by Belowsky's theory the presence in the same specimen of crystals of both varieties, which has been frequently observed, while if we grant to each variety a separate existence, this fact is easily explicable on the basis of the frequent presence of streaks (*Schliere*) in molten magmas, and their consequent want of homogenity in chemical composition.

The plagioclases of the andesites show the same difference between the phenocrysts and the groundmass crystals as in the preceding rocks. The phenocrysts are usually quite clear, and while glass inclusions, often with bubbles, are common and frequently zonally arranged, they seldom show such well developed net forms as have been described above. The phenocrysts show much zonal structure and many twinning lamellæ, which, giving extinction angles of 33° and 34°, show that they are of anorthite, while the smaller lathes, giving angles of 22° to 24°, are of bytownite.

Phenocrysts of biotite are not infrequent, and are in most cases entirely altered to an opacitic aggregate similar to the hornblende. Magnetite is abundant, but calls for no special remark.

Hypersthene-Andesites.—These rocks are characterized by the abundant presence of orthorhombic pyroxene, hypersthene, which

[1] As the Chondos rock seems to be more basic than that of Stavro, it is even probable that its temperature on eruption was less than that of the latter; this would also hold good for the brown hornblende-bearing hypersthene-andesites and the green hornblende bearing dacites.

is often accompanied by augite, occasionally to such an extent that it is difficult to decide whether a given specimen ought to be called a hypersthene-augite-andesite, or an augite-hypersthene-andesite. With one exception, however, it seemed better to group them all under the heading above, especially since the great majority of hypersthene-andesites elsewhere do carry more or less augite, while many augite-andesites are entirely free from orthorhombic pyroxene. The rocks richer in augite will be known as augite-hypersthene-andesite, while those which are quite free from, or very poor in, augite will be called hypersthene-andesite proper. The reason for making this distinction is the greater inasmuch as it corresponds quite exactly with the geographical distribution of the two varieties. The one exception mentioned above is that of a rock entirely free from hypersthene, which is hence a true augite-andesite, and will be described in its proper place.

In some of these rocks, notably in the products of the latest eruption at Kaimeni, hornblende is present in considerable quantity, and as the presence of this hornblende is correlated with structural and other characteristics, these specimens will be described later as hornblende-hypersthene-andesite.

The list of localities at which hypersthene-bearing and hypersthene-andesites occur has been largely increased in the last few years, and their occurrence here is not at all surprising when it is recalled that they occur abundantly at Santorini and Milos and at Erimomilos which are on the same volcanic fracture line. This point will be referred to later.

Hypersthene-andesite proper is found only on Methana, at the top of Mt. Chelona, at and above the acropolis of Methone, around the small harbor of Vathy on the west coast and at one point on the northeast coast. The augite-hypersthene-andesites make up the main mass of Mt. Oros and Mt. Kouragio on Ægina, while the augite-andesite proper is found at Agio Somatos near the Hellenic ruins. These sub-groups resemble each other so much and shade into each other so gradually that they may be described together.

Megascopically they are compact, fine-grained rocks of a rather dark, slightly bluish gray color, the groundmass showing to the naked eye comparatively few small phenocrysts of dull white plagioclase with, at Chelona, a few hornblende needles, and at Oros and Mt. Kouragio a very few rounded colorless quartz grains. They present, on the whole, a decidedly phonolite-like appearance, the resemblance being heightened by the lamellar structure seen on the top of Mt. Oros and at Agio Somatos, and by the sound which many of them give on being struck with a hammer, notably the rock from the south end of Mt. Kouragio. The augite-andesite of Agio Somatos differs slightly from the others in being rather granular in structure, and containing more slender hornblende needles. These rocks do not decompose readily and are quite fresh, except in the case of two specimens from Mt. Oros, which are reddish brown in color.

Under the microscope these rocks show an abundant, often hyalopilitic groundmass, with flow structure well marked; the glass base, which is clear and colorless, except in the Mt. Kouragio rocks where it is light brown, being in relatively small quantity. This glass base seems to be more abundant in the hypersthene-andesites than in the augite-hypersthene-andesites, in one or two of the latter from Mt. Oros the groundmass being almost holocrystalline, with only traces of glass, and in those from Mt. Kouragio the groundmass being rather basaltic with many lathes of plagioclase and hypersthene, and very little interstitial glass base.

The microlites and small crystals of the groundmass are mainly hypersthene, with fewer of plagioclase, many magnetite grains, and in the augite-hypersthene-andesites very many small, approximately equidimensional crystals of nearly colorless augite.

The small hypersthene needles vary in length from 0.02 to 0.1 mm., their diameter being as a rule about one-fifth of the length. They all have parallel extinction, show low domal or pyramidal terminations, and are generally cracked transversely. They are clear and almost colorless, of a very faint greenish

tinge, with feeble but marked pleocroism, ‖ $\dot{c}$ pale greenish gray, ⊥ $\dot{c}$ pale yellow. The hypersthene is the most easily decomposable constituent of these rocks, perhaps owing to the large amount of FeO, and in the more altered rocks (such as those of Mt. Oros) they have almost entirely disappeared, and are only represented by red and brown rectangles and patches of ferrite, or other ferruginous decomposition products.[1]

The plagioclase lathes and crystals of the groundmass show few planes and are usually rectangular in outline. They are either single crystals or simple twins, very few showing multiple twinning lamellæ. As they possess extinction angles of 28° to 31° they belong to the bytownites richer in lime, or even to the anorthites.

A striking characteristic of the hypersthene-andesites proper is their extreme paucity in phenocrysts, especially of the ferromagnesian silicates. Plagioclase phenocrysts occur, but not abundantly, both megascopically and microscopically, but phenocrysts of pyroxene, hornblende or biotite are almost entirely lacking; a circumstance which, together with the facts that hypersthene is abundant in the groundmass, and that the small plagioclase lathes are apparently richer in lime than the phenocrysts, forms another occurrence, in addition to the many already noted, which are not in accordance with Rosenbusch's law that as crystallization proceeds the remaining magma becomes more acid.

Phenocrysts are, however, much more abundant in the other sub-group, and consist chiefly of augite in not well shaped, clear, and almost colorless crystals. Hypersthene in prisms up to 0.8 mm. in length also occurs. The presence of augite seems to have determined, or to be correlative with the presence of hornblende which is almost or quite entirely wanting in the hypersthene-andesites, but rather abundant as phenocrysts in the other group. Originally of a brown color it is invariably altered to an augite opacite aggregate, which is generally quite fine-grained and surrounded by an outer zone of colorless augite with some plagioclase.

[1] *Cf.* FELIX and LENK: Beitr. Geol. Pal. Rep. Mexico, Leipzig, 1890, I., p. 91.

In the Mt. Kouragio rocks, however, it is more coarsely granular and apparently little coherent, as the original crystal outlines are quite lost and the granular masses rounded and washed away by the moving magma.

The plagioclase phenocrysts are of good size and show many more planes than the smaller groundmass crystals. They seldom show twinning lamellæ and the one case where measurement was possible gave an extinction angle of 25°. They bear as inclusions small hypersthene and apatite needles and spots of glass. Some of them show a peculiar core composed of a micropegmatite of what may be either two different feldspars, or particles of the same feldspar, but oriented in two different directions.

In the rock which forms the small hill of the Methone acropolis there are present quite numerous phenocrysts of olivine which can also be seen with the naked eye. These are rather irregular in shape and often broken, though showing traces of crystal faces. They are colorless and quite fresh except on the edges, where they are generally colored bright yellow through incipient decomposition. Such an olivine-bearing hypersthene-andesite also occurs in one specimen from near Vathy Harbor, and from the west slope of Mt. Oros. The last specimen differs from the other rocks of the district in being of a pale brown color, very compact, with subresinous luster and with numerous phenocrysts.

Hornblende-Hypersthene-Andesite.—This has a special interest as it forms the material poured out by the eruption of *ca.* 250 B. C., and hence represents the latest eruptive product of the region. It is also represented by specimens from a loose block on Mt. Chelona and from near Agios Georgios on the northeast coast. The Kaimeni rocks are, however, of the most importance and the following description applies chiefly to them.

They are not very compact rocks, containing numerous pores and in some of the specimens assuming a quite scoriaceous character. They are highly porphyritic, showing, when fresh, a light gray, fine-grained, but dull and not very compact groundmass, with many phenocrysts of plagioclase and black hornblende,

very few biotite tables and still more rarely quartz grains. The scoriaceous specimens are decomposed and have become rather friable and of a dark reddish brown color. The specific gravity was found to be 2.44 in the freshest specimen.

Microscopically they show a hyalopilitic groundmass of colorless glass base with very numerous, almost or quite colorless, hypersthene and fewer plagioclase lathes. Larger, but still extremely small plagioclase and hornblende crystals, together with a few colorless augites, are also present in the groundmass.

The hornblende which occurs as large phenocrysts is generally prismatic, and of a brownish green color, quite fresh and free from alteration. It contains some inclusions of magnetite, plagioclase and a few biotites of large size and is itself inclosed partially by the largest plagioclase phenocrysts. These latter which, judging from the extinction angles on *c* (001) of 35°–38°, are anorthite, are quite fresh but contain many inclusions, chiefly of brownish glass with bubbles, and in one case of very many small flakes of biotite. A few phenocrysts of the latter are also seen, and good-sized grains of magnetite are abundant.

The hornblende-hypersthene-andesites from the other two localities much resemble the above, that from the top of Mt. Chelona differing chiefly by its more typical hyalopilitic structure, the absence of transition forms between the phenocrystic and groundmass crystals and the more vivid green of the hornblende.

Hornblende-Dacite.—This composes the two hills at Anzeiou and Kakoperato in the Oros District on Ægina which seem to be later flank eruptions of the main Oros outflow. The Anzeiou rock is light gray, rather compact and quite free from pores but rough in feel. The groundmass is fine-grained with numerous small hornblende needles. Phenocrysts are very abundant, chiefly white plagioclase crystals with some larger black hornblende prisms and many slightly pink quartz grains, generally rounded, but here and there showing a bipyramidal form, unaccompanied by an augite fringe.

The Kakoperato rock differs somewhat from the other, the phenocrysts which are the same as in the preceding being much

less numerous, though larger, and arranged often in lines of flow. The groundmass is very compact, of a darker, bluish gray color and sub-greasy luster, containing some hornblende needles. The enclosures in this rock, which are very numerous and striking, will be described later. With this Kakoperato rock must be classed the rock near Agio Vesili on the west coast of Ægina, on the ground of its general appearance, though no analysis of it was made and quartz grains are not nearly as abundant as in that just described.

Under the microscope the slides of these occurrences show much the same features.[1] The hyalopilitic groundmass is largely predominant, the glass base being colorless (with no perlitic cracks), and the microlites (which are largely feldspar) showing a beautiful flow structure, but being more abundant in the Kakoperato than in the Anzeiou specimens. Crystals of hornblende and plagioclase and grains of magnetite are also rarer in the groundmass of the former while abundant in the latter. Many of the microlites and lathes of feldspar in the Kakoperato dacite are untwinned and show parallel extinction which points to the presence of orthoclase, belief in which being strengthened by the comparatively large quantity of K_2O shown on analysis. It is noteworthy that neither in these nor in any of the other dacites was quartz met with as a groundmass constituent.

The phenocrysts are chiefly hornblende and plagioclase, only a few quartz sections being found in the slides. Magnetite is present, though not abundantly, in rather large, well shaped grains which must be classed rather with the phenocrystic than with the groundmass constituents.

The hornblende which occurs only as phenocrysts is in small but well shaped crystals, often broken. In color they are brownish green (that of Agio Vesili is greenish brown) and quite fresh and unaltered. Rare inclusions of plagioclase, augite, and magnetite are found. In general character and habit they much resemble the hornblendes of the Stavro rock, though the color is more inclined to brown.

[1] On the whole the slides much resemble those of the dacite from Lassen's Peak in my possession.

The large plagioclase phenocrysts are quite fresh and clear and many show a "network" core of glass. Twinning lamellæ are not very common, and, as the angles observed were small, the phenocrysts are referable to labradorite, though in some cases they seem much more basic.

The few quartz sections are rounded and irregular, perfectly clear but much cracked and with few inclusions of glass. One small perfectly hexagonal section was seen. A few small colorless prismatic augite phenocrysts were noted as well as some dark green biotite tables, one of which contains a colorless zircon.

Hornblende-Hypersthene-Dacite.—It would be more in accordance with Zirkel's definitions to call these rocks quartz-pyroxene-andesites since he reserves the name dacite for the more acid or quartz-bearing hornblende or biotite-andestites.[1] On the other hand Rosenbusch[2] does not put these limits on the dacites, but includes among them very acid or quartz-bearing pyroxene-andesites. I am inclined to favor his view since the presence or absence of quartz or superabundant silica seems to me a consideration of much more weight than the nature of the ferro-magnesian silicate, and this, together with the presence of *green* hornblende in the most typical specimens, has decided me in giving them the name they here bear; they being called as they are owing to the greater abundance and importance of the hypersthene over the hornblende, none of the latter appearing as a groundmass constituent.

These rocks are the most abundant of any species on Methana, most of the mountain masses around Mt. Chelona being formed of them. Specimens were collected and examined from near Vromo, from the ridge south of Mt. Chelona, Mt. Chorsa to the northwest of Chelona near Panagia on the northwest coast, and from the neighborhood of Kosóna, both near the town and between it and Mt. Chelona; and, further, my notes show that the rock along the coast between Kosona and Vromo

[1] ZIRKEL. Op. cit. II., p. 569.

[2] ROSENBUSCH, Mikr. Phys. II., 1887, p. 634.

Limni are the same as at the former place; so that it is seen that the whole southern part of the peninsula (with the exception of the district around Methone and Megalo Chorio), with much of the northwest, north and east are of these rocks.

These do not show as much quartz as the other dacites, that from near Panagia especially being quite free from it, though its high silica content (64.83 per cent.) shows that it belongs here. Megascopically they much resemble the dacite of Anzeiou, being not very compact, light-gray rocks with very numerous phenocrysts of plagioclase and hornblende, and fewer colorless or pinkish quartz grains. The Panagia specimen is much more compact and finer grained than the others, and phenocrysts are smaller and less abundant. Endogenous enclosures are not rare, especially in the rock about Kosona.

Under the microscope there are seen to be three distinct types. The Kosóna specimens resemble much the hornblende-dacite of Anzeiou, the groundmass being typically hyalopilitic with colorless glass base. The hornblende is bright olive-green and perfectly fresh. Hypersthene, besides composing the great majority of the groundmass microlites, occurs in good-sized prisms as phenocrysts, which show all the optical characters already mentioned. Magnetite also occurs in large and small grains, but is rare as a true groundmass constituent. Some small colorless augite crystals are also seen. The plagioclase, which occurs chiefly in large poorly shaped phenocrysts, many with glassy "net" cores, shows many twinning lamellæ; and the extinction angles of 25° and even less show that it is a bytownite rich in soda. They contain very many apatite needles. Biotite is very rarely seen in the slides, one large, clear, greenish gray prism being much corroded, and altered at the edges to a very coarse granular mixture of augite, plagioclase and magnetite. This alteration had chiefly taken place in the zone of the prisms and pinacoids, the basal plane being sharp and quite fresh.

The second type is that presented by the specimens from the southern and western parts of Methana (with the exception of the Panagia specimen). These are characterized by a very dusty

brown groundmass, the base being colorless glass which is filled with an infinite number of grains of "dust" and small microlites, generally short, stout and rarely long (as usual). These microlites are chiefly augite and hypersthene, little plagioclase being represented. Besides these microlitic constituents there are small lathes and rectangular sections of plagioclase, small augite and hypersthene crystals and some magnetite.

The hornblende phenocrysts in these rocks are yellowish brown in color, and often altered on the outer edges to an augite opacite aggregate. Hypersthene crystals are common, but not as large as in the preceding type. In one specimen, which shows signs of decomposition, they are either entirely or partially changed to rusty or reddish brown secondary products. The plagioclase, whose sections are generally rhombic or rectangular, is similar to that of the preceding. A few clear, corroded and cracked quartz grains are seen.

The third type is only represented by the Panagia specimen, which also differs from the others megascopically. The groundmass here seems to be chiefly microfelsite with little or no glass. In the microfelsitic base are many minute magnetite grains, and flecks and microlites of feldspar, part of which may be orthoclase, as indicated by the parallel extinctions. As the percentage of K_2O is small, however, it seems more probable that this is labradorite, or oligoclase. Hypersthene is not abundant in the groundmass.

The phenocrysts are not numerous and consist of brown hornblende, altered as before described, with some plagioclase and hypersthene, which call for no special comment. There are numerous spots of tridymite, which seem to be an essential and not a secondary constituent.

It must be remarked that the position of this Panagia rock is an uncertain one on the whole, and I would call it a trachyte were its percentage of K_2O not so very much lower than that of any other trachyte analysis.

Biotite-Dacite.—This dacite, whose occurrence is described on page 806, Vol. II., is only found on the mainland, and all the

specimens examined come from the railroad cutting near the hamlet of Kolautziki. A short petrographical description by Dr. R. Lepsius, which will be referred to later, will be found on page 604 of Philippson's "Peloponnes."

The specimens show a fine-grained, but not very compact, very light gray or light brown groundmass which contains many minute black biotite flakes and feldspar and quartz grains. In this are thickly scattered larger phenocrysts of colorless feldspar, small biotite tables and grains or bi-pyramids of pink or amethystine quartz, which on the weathered surfaces have entirely lost their color. These crystals do not show much definite arrangement in lines of flow.

Under the microscope they show a highly vitreous groundmass traversed by numerous perlitic cracks, and containing few microlites, but flow streaks of brown or greenish dusty matter. In the groundmass also lie many small flakes of olive-green biotite, with some small plagioclases and still fewer small quartz grains which are arranged in lines of flow. Hardly any magnetite is present.

The phenocrysts are of biotite, quartz, and feldspar. The first are not very large hexagonal tables, olive-green when fresh, but banded or mottled with reddish brown in the decomposed specimens. They are very poor in inclusions, only a few plagioclases and zircons being thus met with. Clear, colorless quartz grains are common, generally with rounded outlines, though occasionally showing crystallographic boundaries. They are quite free from inclusions, no glass being noted and only a few colorless zircons.

The feldspar phenocrysts which contain few inclusions of glass, biotite, and zircon in almost every case are plagioclase, though many of them are simple crystals, and twinning lamellæ are rare, one case giving angles which indicate labradorite. Though Lepsius makes the prevailing feldspar out to be sanidine, and hence calls the rock a "quartz trachyte," my own observations fail to confirm this. Though the crystals are generally simple and clear and hence look like sanidine, careful

search failed to diclose more than a very few which gave parallel or approximately parallel extinction. Moreover, the chemical composition of the rock is that of a typical dacite, and not at all that of a quartz-bearing trachyte or rhyolite.[1] The percentage of K_2O (1.66) is much too low for a rhyolite as rich in orthoclase as Lepsius makes out the rock to be. The percentage of CaO (2.98) again is much higher than that shown by any other rhyolite analysis, while quite in accordance with other dacite analyses. It is true that it is the lowest lime percentage of any of the rocks of the district, but this is quite in accordance with the comparative scarcity of feldspar, and its position in the albite-anorthite series. For these reasons the feldspar is held to be a plagioclase, and the rock is consequently a dacite.[2]

Tuff.—Only two specimens of this fragmental rock were collected. That from the west end of Mt. Chondos is light gray in color, rather finely granular, very friable, and shows evidence of stratification. Under the microscope it is seen to be composed of fragments of fresh olive-green hornblende, plagioclase crystals, magnetite grains, a few colorles augite crystals, and much microlitic groundmass with colorless glass base, patches and streaks of brown dusty material being very abundant, and there being no definite order in the arrangement of the above fragmentary constituents. No remains of organic beings, either animal or vegetable, were to be seen, and the specimen is evidently a tuff of the light gray hornblende-andesite deposited subaërially.

The brown compact tuff from farther east, near the top of the Chondos ridge, offers more points of interest. Megascopically it is very compact and fine grained, light brown and with a subgreasy luster. In this main mass are many rounded enclosures of a gray porphyritic hornblende-dacite, showing hornblende, plagioclase, and quartz phenocrysts, and resembling the dacite of Kakoperato.

Under the microscope the tuff shows a brecciated structure

[1] *Cf.* Analysis 15, in Part III.

[2] ZIRKEL (Op. cit. II. p. 258), on the authority of Lepsius, classes these rocks, as well as the hornblende-andesite of Poros, with the rhyolites.

composed largely of small angular fragments of the hornblende-augite-andesite of the Monastery district, with pieces of the brown hornblende, colorless augite, and plagioclase that occur in these rocks, this fragmentary material being cemented by a clear, colorless isotropic substance. Since chemical analysis (*cf.* No. 16, Part III.) shows that this tuff is very acid, containing 70.81 per cent. of silica, and since the rock of which the breccia fragments are composed contains only about 55 per cent. of silica, it seems certain that this glassy cementing substance is a form of amorphous silica, such a silicification of eruptive rocks being a not at all unusual phenomenon. This tuff is also, like the preceding, of subaërial origin. Through a misunderstanding no slide of the gray enclosures was made, but, as they present the megascopical characteristics of the Kakoperato dacite, they may be safely classed as analogous to these, though an analysis giving 71.49 per cent. of silica shows that they also have been subjected to the silicifying process.

The only other eruptive rocks found on Ægina were a block of a hard, greenish, aphanitic hornfels-looking rock which on examination proved to be a porphyry; a small rounded loose block of a coarse-grained biotite-granitite, with rather gabbro-like structure, and which probably came from one of the Cyclades as ballast; and many rounded fragments of white pumice found on the beaches of Ægina and Methana which undoubtedly have floated from Santorini, as they present the characters of this pumice, which I found on my visit there floating in large quantities in the inner bay of the island group.

HENRY S. WASHINGTON.

(To be continued.)